

**EXAMINING THE SEVERITY OF MOTOR VEHICLE CRASHES
INVOLVING ROADSIDE BARRIERS ON HIGH SPEED ROADS**

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Examining the Severity of Motor Vehicle Crashes Involving Roadside Barriers on High Speed Roads. (May 2015)

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With the implementation of posted speed limits greater than 75 mph in some states across the nation, there is an increasing interest among the roadside safety research community regarding the relevance of existing testing criteria used to evaluate the effectiveness of roadside safety barriers that are placed on such roads. Current crash test guidelines are contained in the Manual for Assessing Safety Hardware (MASH), which defines 62 mph being the 85th percentile impact speed for high speed roads. A crash data analysis of state highways and interstates in Texas with posted speed limits of 70, 75, 80, and 85 mph was performed to investigate whether MASH's current test guidelines are applicable for roadside safety appurtenances placed on roads with posted speed limits greater than 75 mph. A representative sample of real-world, single-vehicle, run-off-road crashes involving longitudinal barriers as the first harmful event for years 2010 - 2013 was extracted from the Texas Department of Transportation's (TxDOT) CRIS crash database. The need for a higher testing impact speed was investigated by determining whether the injury severity factor significantly increased as the posted speed limit increased for real-world vehicle accidents against longitudinal roadside safety barriers designed for 62 mph oblique impacts. As posted speeds continue to rise, it is important to know that the structural integrity of safety barriers is being tested at representative speed levels of real-world data since it has a direct

impact on human life. At the 5% significance level, the fatal and incapacitating injury severity percentage was not statistically different between 70 mph and ≥ 80 mph for years 2010 – 2013. However, the combined crash data for all four years did show an increase and statistical significance between the percentages at the 5% level. This suggests that the 85th percentile impact speed for real-world crashes occurring on posted speed limit roads of ≥ 80 mph could be higher and that future work could support this finding. Future work, including looking at data for more years once they become available and the reconstruction of crashes to find actual impact speed, would provide a more conclusive statement.

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temporary highway safety features and recommended evaluation criteria to assess test results” are outlined in the Manual for Accessing Safety Hardware (MASH) (2009). This report also defines different test levels based on the type of impact conditions and employed test vehicle. Test Level 3 (TL-3) is the basic test level that specifies both the passenger cars and pickup trucks impacting at an angle of 25 degrees and a speed of 62 mph (MASH, 2009). This impact speed was derived from crash data collected on roads with design speeds up to 70 mph. This impact speed and angle combination happens to represent “approximately the 92.5 percentile of real-world crashes” (MASH, 2009). The highest impact speed used for testing (62 mph) has not changed since the previous guideline, NCHRP Report 350, dated 1993 and is currently in use for all roads with a 70 or greater mph posted speed limit. Fitzpatrick et al. (2007) evaluated the criteria for high design speed roads up to 100 mph based on Report 350 and found that the impact angle of 25 degrees does “not vary significantly with functional class.” Therefore, the focus of this project was to examine whether or not the testing impact speed should be raised for roadways with posted speed limits higher than 70 mph.

There have been tests performed, both computer-simulated and real-life, involving higher speed impacts against barriers that have passed MASH TL-3 specifications. Sheikh et al. (2009) performed computer simulations to evaluate roadside safety hardware for high speed applications and found issues as the impact speed increased. Bligh et al. (2010) performed full-scale crash tests against a bridge rail and guardrail at 85 mph and found stability concerns associated with the bridge rail, while the guardrail did not successfully contain and redirect the vehicle. Although it has been shown that there are structural integrity concerns associated with higher speed impacts, there might not be a reason to increase the testing impact speed of roadside safety

barriers if drivers are not actually impacting at very high speeds. Unfortunately, information about the impact speed of the vehicle during a crash incident is not provided in crash databases. Information about the actual impact speed of the crash can only be obtained through the reconstruction of crashes and looking at police reports which is time-consuming and requires special training. Therefore, to more quickly determine whether current roadside safety barriers are acceptable for use on high speed roads, the severity of injuries for each high speed road limit (70, 75, \geq 80 mph) was examined since it has been shown that very high impact speeds with the barrier can cause structural integrity concerns.

Crash statistics were examined for the state of Texas. Since Texas is home to some of the highest speed limits in the nation, examining crash data for Texas provided the opportunity to compare crash severity statistics for roads with posted speed limits up to 85 mph. Crash data was provided from the Texas Department of Transportation's (TxDOT) Crash Records Information System (CRIS) database. The crash data was filtered to include 2010-2013, single-vehicle and single occupant run-off-road crashes happened on all types of highways with a posted speed limit of and greater than 70 mph. Accidents were selected with the first harmful event being a fixed object, specifically a roadside safety barrier (median barrier, concrete traffic barrier, guardrail, retaining wall, bridge rail). Crash latitude and longitude were provided, as well as injury severity description. Since the 85 mph speed limit was implemented in 2012, an analysis performed on more recent years would include more data on crashes on higher speed limit roads. Before 2010, many of TxDOT's CRIS crash data entries had missing information. In order to ensure that the same information could be compared across the years, years 2010 and beyond were analyzed. The analysis only focuses on single occupant (driver) crashes to simplify injury classification.

With the CRIS database including only a total of fourteen crashes happened on 85 mph posted speed limit roads in the year 2013, the search was expanded to include multiple vehicles with multiple occupants. However, since this search only brought up three additional crashes, it was determined that the ‘single occupant’ restriction did not substantially limit the available data.

One drawback with the crash data was that it did not provide information on the most harmful event. Although a collision with a barrier was the first harmful event, it is unknown whether the vehicle also impacted an additional object which might have caused the reported injuries.

However, it is known that the injuries were not due to an accident with another motor vehicle because the data was filtered to include accidents with only one motor vehicle. Although the occupant injuries may have not been caused by an impact with the longitudinal barrier (e.g., a vehicle could have rolled over after hitting the barrier, which led to the fatality), the purpose of the barrier should have been to safely contain and redirect the vehicle and keep it from colliding with other objects beyond the barrier. Consequently, a high injury severity could be interpreted as barrier failure to safely redirect the vehicle and may suggest that the impact speed was higher than the 62 mph value the barrier was initially designed for. Within the scope of this analysis, no investigation has been and will be carried on the orientation of impact against the longitudinal barrier. Information on the impacting angle is not included in the CRIS database and might be available only through police reports for specific crashes. Time and budget constraints of this project would not allow such an in-depth investigation of the accidents.

This report describes how the crash data were obtained, details the overview and specific analysis of the data, and draws conclusions based on the results. The report is divided into three

chapters: Chapter II documents the results of the exploratory analyses of the data. It provides an overview of the data collected in this project. Chapter III details a crash severity analysis and provides conclusions of a statistical analysis. Chapter IV gives a summary of the report and discusses future work.

CHAPTER II

CHARACTERISTICS OF DATA

This chapter presents an overview of the data collected in this project. The chapter is divided into two sections. The first section describes how the data were collected and assembled. The second section presents a summary of the data collected.

Data Collection Process

Crash data was extracted from the TxDOT's CRIS database by a staff at the Texas A&M Transportation Institute, who was cleared by the Texas A&M Institutional Review Board (IRB) to review such information. CRIS is a "statewide automated database for all reported motor vehicle traffic crashes received by TxDOT" ("Crash Data Analysis and Statistics"). The records are kept for the past five calendar years plus the current calendar year. Crash data were collected from this database in order to obtain crash data from Texas since it is home to some of the fastest speed limits in the nation. Examining crash data from Texas provides insight on the structural integrity of longitudinal barriers on high speed roads without having to examine crash data from all the states. First, a request to use the crash data was sent in to TxDOT. Once approved, the staff described above was able to extract the data from CRIS based on the requested categories.

Several variables were used to extract the data. The "crash date" included years 2010-2013. Before 2010, there was an inconsistency on what types of data were recorded. The "crash speed limit" included all types of roadways with a posted speed limit of and greater than 70 mph, the "first harmful event" was set as a fixed object, and the "object struck" was against a specific type

of longitudinal barrier (median barrier, guardrail, retaining wall, bridge rail, concrete traffic barrier). The “crash severity” variable included categories such as unknown, not injured or property damage only (PDO or O), possible injury (injury type C), non-incapacitating (injury type B), incapacitating injury (injury type A), and fatal (injury type K). “Person count” was set to one to ensure that only single occupant run-off road crashes were included to make it easier to classify the injuries, and the “manner of collision group” was set to one motor vehicle. These two extra constraints did not greatly limit our received data as only three extra crashes were reported on 85 mph in 2013 when the data included multiple occupants and multiple vehicles. Variables involving location of the crash were also extracted. These variables included the “roadway system” the crash happened on, the “crash longitude and latitude”, the “city”, the “county”, and the “crash control section”. Specifics about the road where the accident occurred were also extracted. This information included the “roadbed width” and the “total paved width”. The “crash contributing factor list” gave the cause of the crash. After receiving all of the data under these different variables, specific variables that would provide the best insight to the scope of this project were chosen. The main characteristics of this data are outlined in the next section.

Summary of Characteristics of Data

Table 1 shows a summary of the number of total crashes against concrete traffic barriers, guardrails, bridge rails, median barriers and retaining walls for each year and speed limit. Several entries did not have information on the speed limit of the road. These were omitted in the future analysis of data. Table 1 shows an increase in the number of crashes against barriers throughout the years for 75, 80, and 85 mph roads. A portion of the increase can be attributed to the number of highway segments that had a posted speed limit above 70 mph. Since only the year 2013

included crash data for 85 mph posted speed limit roads, it was decided to combine crash data for 80 and 85 mph roads into one category (≥ 80 mph) to be able to compare statistics throughout the years.

Table 1: Number of Barrier Crashes by Speed Limit and Year.

	2010	2011	2012	2013	Total
No Speed Limit Data	4	5	63	288	360
70 mph	1601	1696	1795	1442	6534
75 mph	7	27	910	2012	2956
80 mph	14	23	51	106	194
85 mph	-	-	-	14	14
Total	1626	1751	2819	3862	10058

Table 2 shows the breakdown of the number of crashes according to posted speed limit, year, and barrier category. The table shows that most crashes occur against median barriers and guardrails which can most likely be attributed to their frequency of placement on high speed roads. The number of crashes reported against guardrails and median barriers were also very similar. Guardrails and median barriers also reported the highest number of barrier crashes on ≥ 80 mph posted speed limit roads.

Table 2: Number of Crashes against Each Type of Barrier.

	2010			2011			2012			2013			Total
	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	
Concrete traffic barrier	550	-	2	526	14	1	417	171	3	162	110	7	1963
Guardrail	643	3	7	866	11	17	835	406	33	417	394	39	3671
Median barrier	284	4	3	188	2	3	328	273	9	627	1304	45	3070
Retaining wall	56	-	1	64	-	-	141	31	2	106	19	4	424
Hit end of bridge	4	-	-	2	-	-	9	2	1	5	3	-	26
Hit side of bridge	64	-	1	50	-	2	65	27	3	125	182	25	544
Total	1601	7	14	1696	27	23	1795	910	51	1442	2012	120	9698

Table 3 shows the number of crashes for each roadway type. For crashes on highways with greater than or equal to 80 mph speed limits, all occur on interstates, state highways, or toll roads. Overall, most crashes occur on interstates. Consequently, it was decided to only focus on the crash severity of crashes occurring on state highways and interstates since they would provide the best comparison of injury severity for all three speed limit categories and are the two more common types of highways in Texas.

Table 3: Number of Barrier Crashes for Each Roadway System.

	2010			2011			2012			2013			Total
	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	
Alternate	1	-	-	1	-	-	-	-	-	6	-	-	8
Business Interstate	3	-	-	1	-	-	3	-	-	1	-	-	8
Business US	-	-	-	-	-	-	1	-	-	4	-	-	5
County Road	-	-	-	-	-	-	1	-	-	-	-	-	1
Farm to Market	55	-	-	52	-	-	71	1	-	81	6	-	266
Interstate	739	4	14	780	14	23	560	814	38	355	1359	89	4789
Local Road/Street	6	-	-	9	-	-	7	2	-	14	4	-	42
Ranch Road	1	-	-	1	-	-	-	26	-	1	-	-	29
Spur	1	-	-	2	-	-	-	-	-	-	2	-	5
State Highway	179	-	-	194	3	-	321	-	7	216	214	13	1147
State Loop	38	-	-	37	1	-	54	2	-	82	11	-	225
Toll Road	286	-	-	296	5	-	292	9	6	336	29	18	1276
US Highway	292	3	-	323	4	-	485	56	-	346	387	-	1896
Total	1601	7	14	1696	27	23	1795	910	51	1442	2012	120	9698

Table 4 shows the number of barrier crashes that occurred in each Texas County for ≥ 80 speed limit road crashes. Most of these crashes occurred in Hudspeth and Reeves County. Both of these counties are located in west Texas which is less densely populated. This would explain why both of these counties could have more roads with a ≥ 80 speed limit which would lead to a higher frequency of reported crashes.

Table 4: Number of ≥ 80 mph Road Barrier Crashes per Texas County.

	2010	2011	2012	2013	Total
Hudspeth	1	9	8	14	32
Reeves	3	2	8	17	29
Kimble	1	2	9	12	24
Travis	-	-	9	14	23
Sutton	1	3	4	13	21
Ward	-	3	3	11	17
Crockett	3	2	2	6	13
Pecos	3	-	2	6	11
Guadalupe	-	-	-	9	9
Kerr	-	2	2	5	9
Williamson	-	-	5	2	6
Culberson	-	-	-	5	5
Caldwell	-	-	-	5	5
Harris	1	-	-	1	2
Dallas	1	-	-	-	1
Jeff Davis	-	-	-	1	1
Total	14	23	51	120	208

Chapter Summary

Crash statistics for the state of Texas were obtained using the CRIS database with TxDOT's permission. After compiling the data, it was observed that only 2013 had reported crashes on 85 mph posted speed limit roads, so all subsequent data collection combined crashes that happened on 80 and 85 mph roads into one ≥ 80 mph category to better compare across the years. Most crashes were found to occur against guardrails and median barriers which could be attributed to their higher frequency in the distribution of barriers on highways. Crash severity across the speed limit categories will only be compared for crashes occurring on state highways and interstates since these were among the few roadway types to have reported crashes on the ≥ 80 mph category and are the more common types of highways. An analysis of ≥ 80 mph road barrier crashes showed that most crashes occur in Hudspeth and Reeves counties.

The following chapter will include a visual analysis of the injury severity of crashes, summary statistics involving injury severity for each speed limit and year, and provide an analysis from the results.

CHAPTER III

CRASH SEVERITY ANALYSIS

This chapter describes the relationship between the injury severity of crashes and the effectiveness of the roadside safety barriers. The chapter is divided into three sections. The first section provides a description of the characteristics of the crash severity data. The second section presents an exploratory analysis of the data using geocoded maps. The third section shows the crash severity analysis as a function of the posted speed limit.

Data Collection

The crash data were filtered to only include those crashes occurring along interstates and state highways in order to better access the injury severity level across all years for the 70 mph, 75 mph, and greater than or equal to 80 mph speed limits. According to Table 3 in Chapter II, interstates and state highways had among the highest number of total reported crashes and reported crashes on ≥ 80 mph posted speed limit roads. Consequently, a crash data analysis of the crashes occurring along these types of roads would give the best representation of changes in injury severity level for all speed limit categories.

The injury severity of each crash was classified according to the KABCO scale, which is used by police officers to categorize the injuries of a victim at a crash scene. These categories include fatal (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and property damage only (O), as originally described above. The injury severity level of the person involved in the crash is decided upon by the police officer at the crash scene. The injury severity

level reported in the CRIS database is based on the police officer's report. Without access to the police reports filled out at the crash scene, knowledge of exactly what type of injuries fit into each of the categories was not attained. For this study, a reported fatal or incapacitating injury was assumed to be an obvious severe injury that resulted from the crash with the barrier.

Mapping Crash Data

All following maps of Texas only plot crashes occurring along state highways and interstates using ArcMap 10.2. Some of the crash data entries from the CRIS database had incomplete information. These were most likely caused by a reporting error, or the information was unknown. Table 5 shows the total number of reported crashes for state highways and interstates, and how many of the total crash data entries on these roads reported incorrect coordinates of (0,0) or an unknown injury severity level. All maps were created using known information.

Table 5: Road Barrier Crashes on State Highways and Interstates.

	Total Crashes	Crashes with (0,0) coordinates	Crashes with Unknown Injury Severity Level
2010	936	42	15
2011	1014	61	17
2012	1766	91	45
2013	2247	125	73
Total	5963	319	150

Figure 2 shows a sequence of plots with crashes occurring on 70 mph posted speed limit state highways and interstates for all four years. From the figure, it can be observed that one particular curved section of road of I-20 in the middle of Texas constantly reported to have a large number of crashes every year between 2010 and 2012. The reason it is not seen in the last picture of Figure 2 could be because the speed limit was raised on that section of highway.

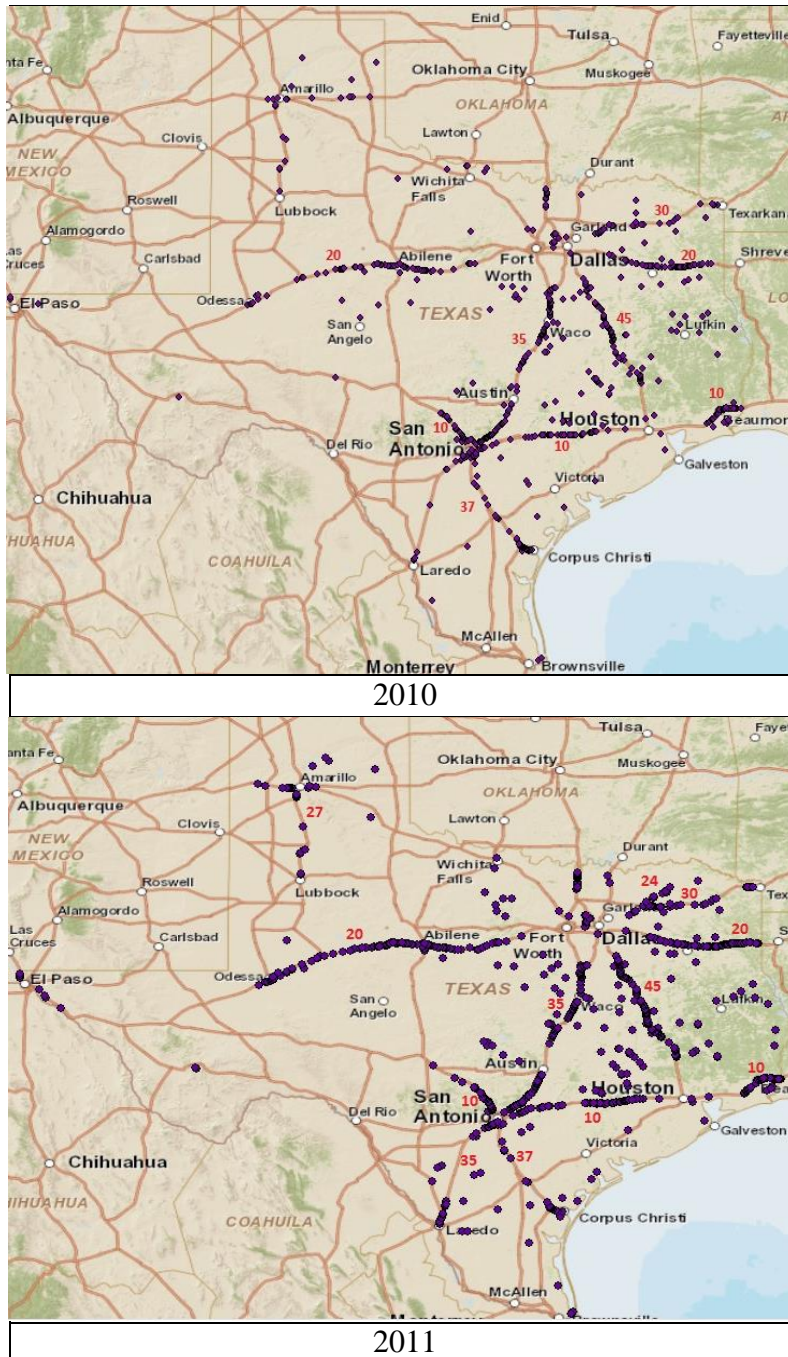
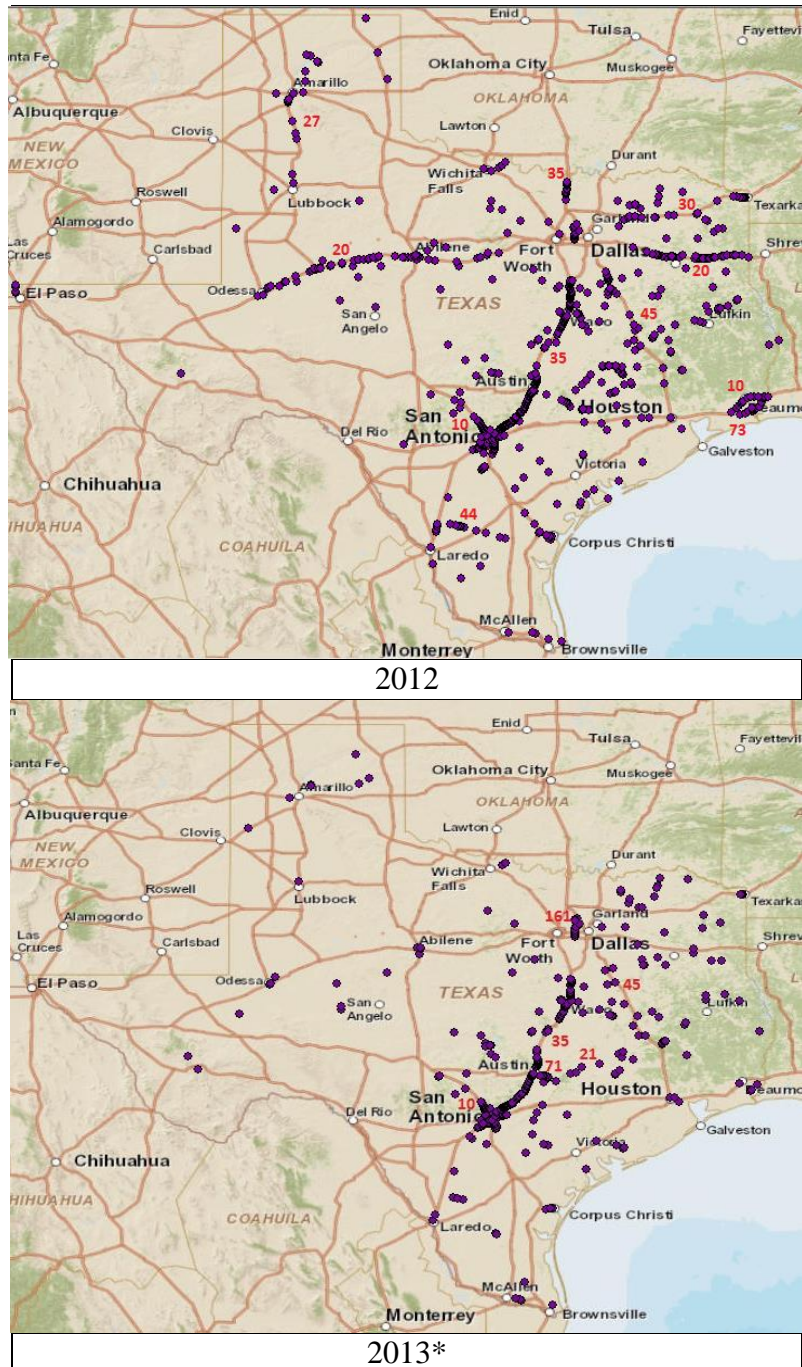


Figure 2: Plotted Road Barrier Crashes on 70 mph State Highways and Interstates.



*Note: Patterns look different because some speed limits were increased.

Figure 2 Continued.

Figure 3 shows a sequence of plots with crashes occurring on 75 mph posted speed limit state highways and interstates for all four years. From the figure, it can be observed that the number of crashes significantly increased between 2011 and 2012. This could be due to the number of new

freeways with a 75 mph posted limit. The same section of I-20 that had frequently reported crashes in Figure 2 reappears in the last two shots of Figure 3, suggesting that the posted speed limit for the road segment was increased.

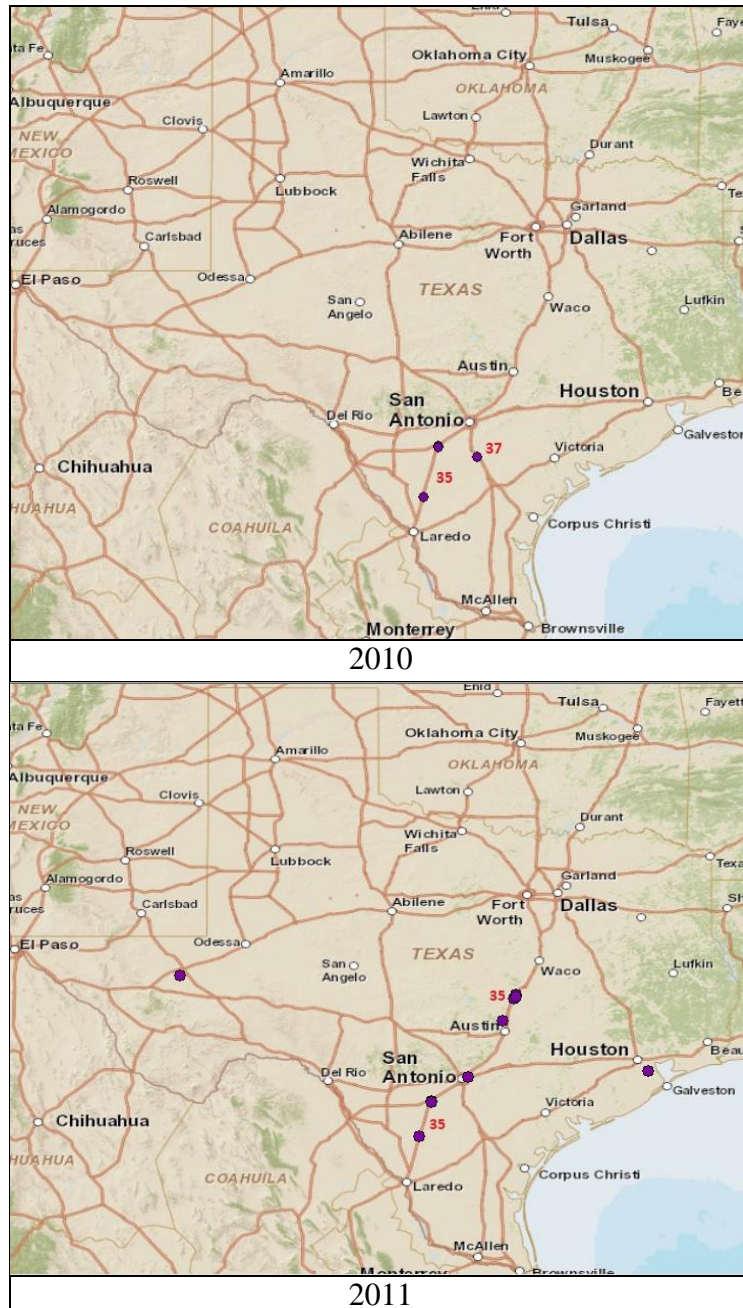


Figure 3: Plotted Road Barrier Crashes on 75 mph State Highways and Interstates.

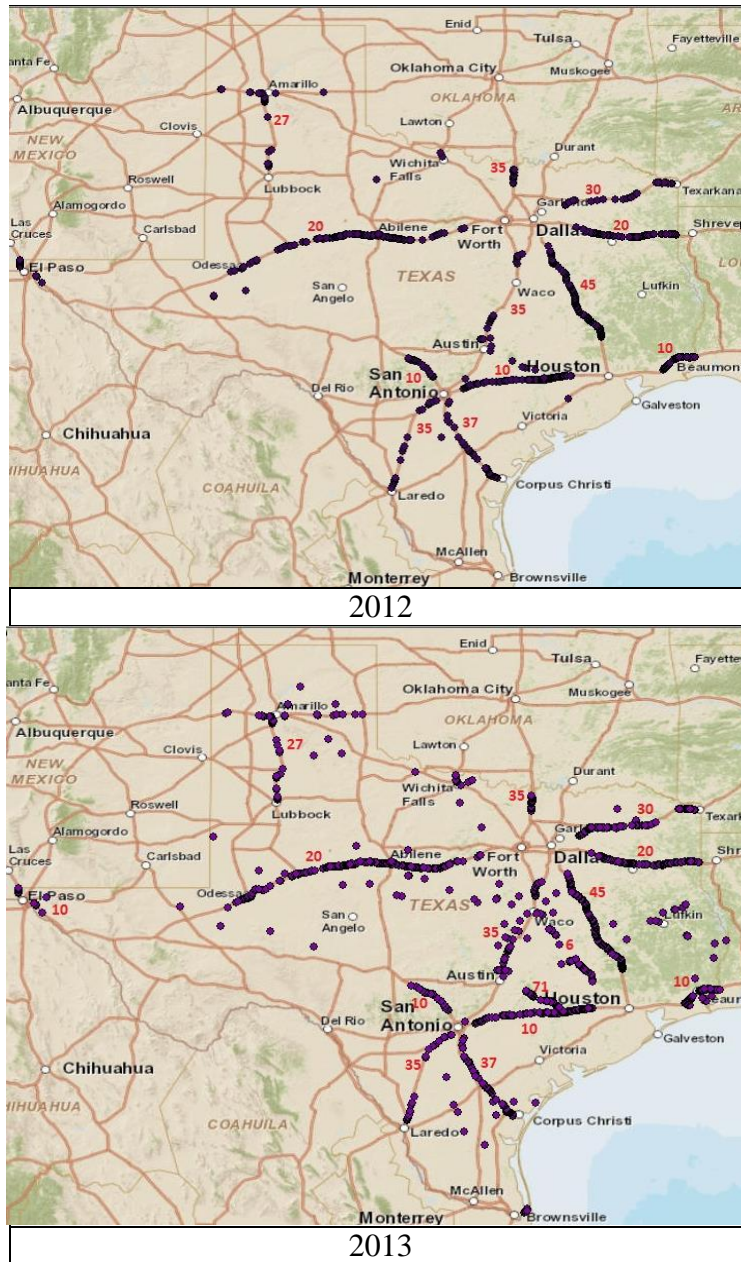


Figure 3 Continued.

Figure 4 shows a sequence of plots with crashes occurring on ≥ 80 mph posted speed limit state highways and interstates for all four years. From the figure, it can be observed that the frequency of crashes greatly increased from 2010 to 2013 for the same highways. Highway 130 in Austin is the only road in Texas with an 85 mph speed limit. Crashes for this road can be seen in 2012 and

2013. The crashes shown in 2012 for this road were for an 80 mph posted speed limit, and the crashes in 2013 were on an 85 mph posted speed limit. There was an increase in crashes for 130 between those years following an increase in speed limit.

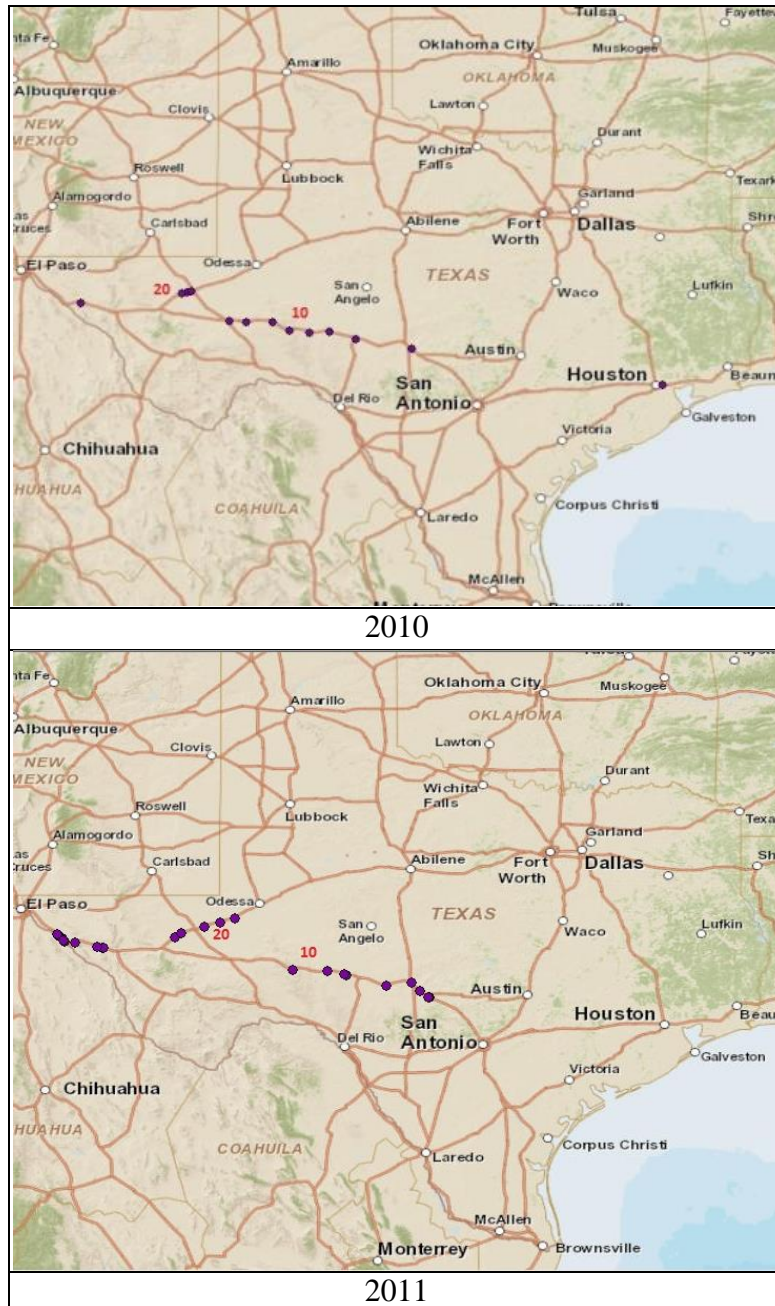
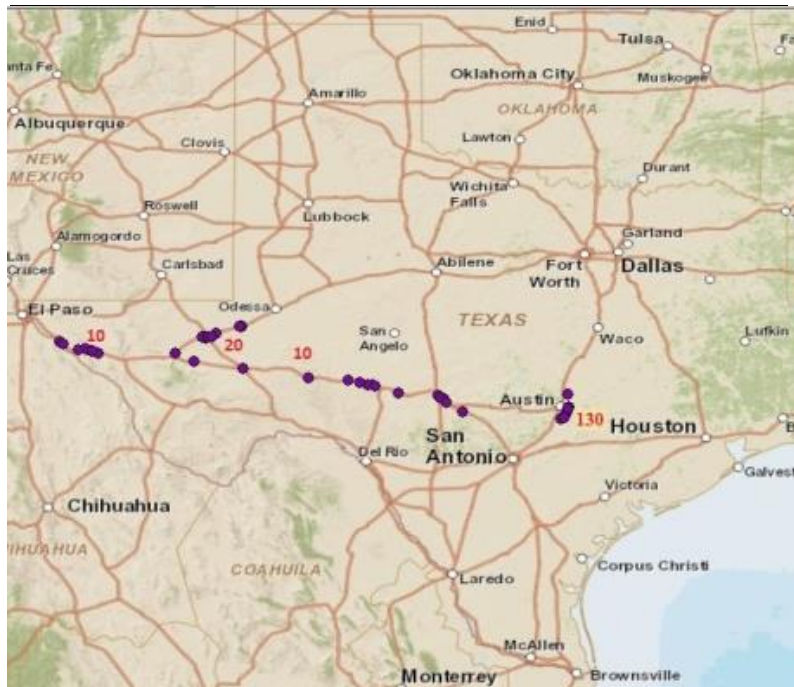
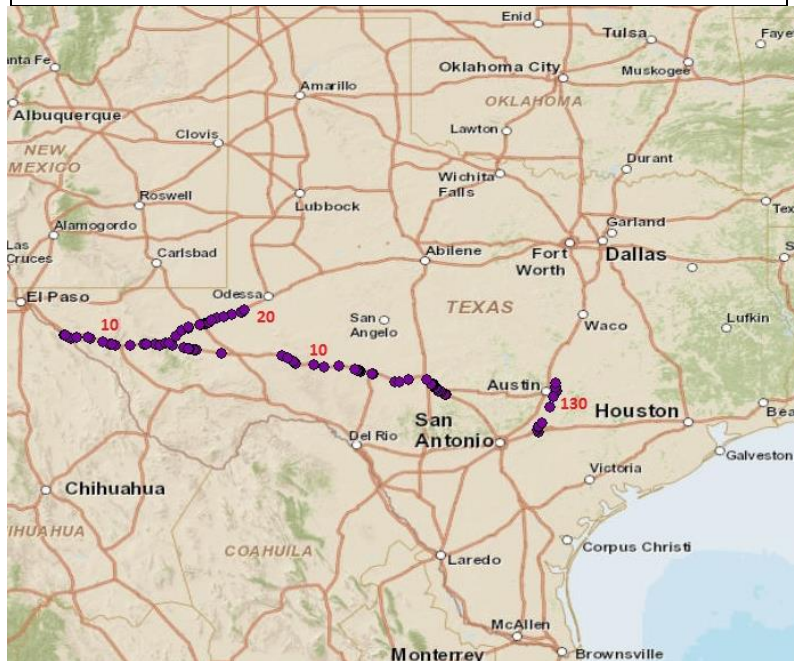


Figure 4: Plotted Road Barrier Crashes on ≥ 80 mph State Highways and Interstates.



2012








2013

Figure 4 Continued.

Figures 5-7 show plots of crashes on state highways and interstates color-coded by injury severity level. The crashes listed with a crash severity level of ‘unknown’ were not plotted. The

legend for the color scale of the pins is shown in Table 6. The corresponding KABCO injury severity letter classification is also given. For this project, severe injuries were considered for any crashes with a K or A classification.

Table 6: Injury Severity Color Scale Legend.

Color	Injury Severity	KABCO Scale
	Fatal	K
	Incapacitating Injury	A
	Non-Incapacitating Injury	B
	Possible Injury	C
	Property Damage Only	O

Different symbols were chosen to plot the data based on how to better show the differences in injury severity. The name of the highways are indicated next to the highway in red. Figure 5 shows a sequence of plots with crashes occurring on 70 mph posted speed limit state highways and interstates, color-coded by injury severity level, for all four years. From the figure, it can be observed that all of the fatal and incapacitating injuries are scattered throughout the state. The number of fatal and incapacitating injuries appears to be the greatest in 2011, with I-20 showing the most fatal injuries.

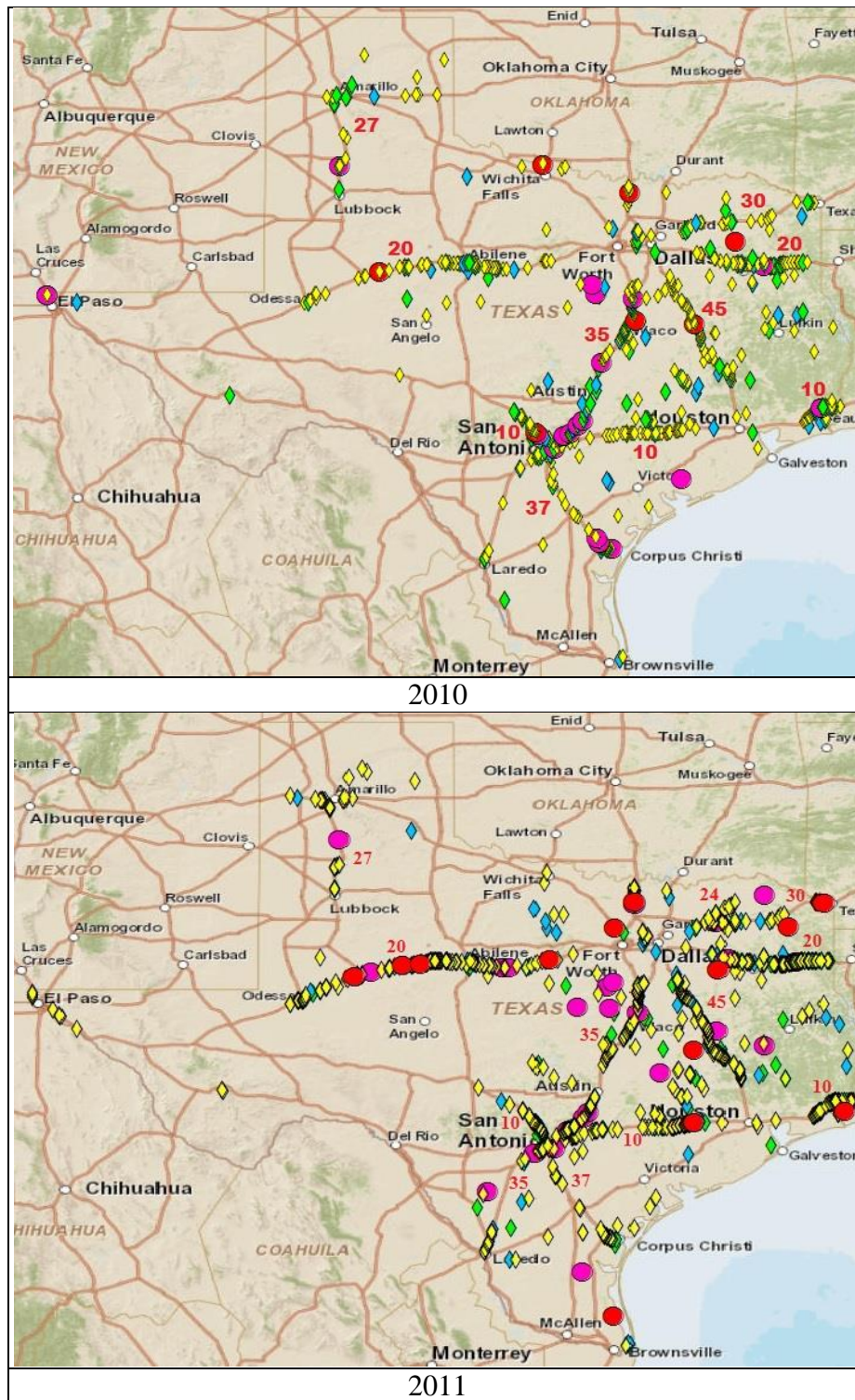
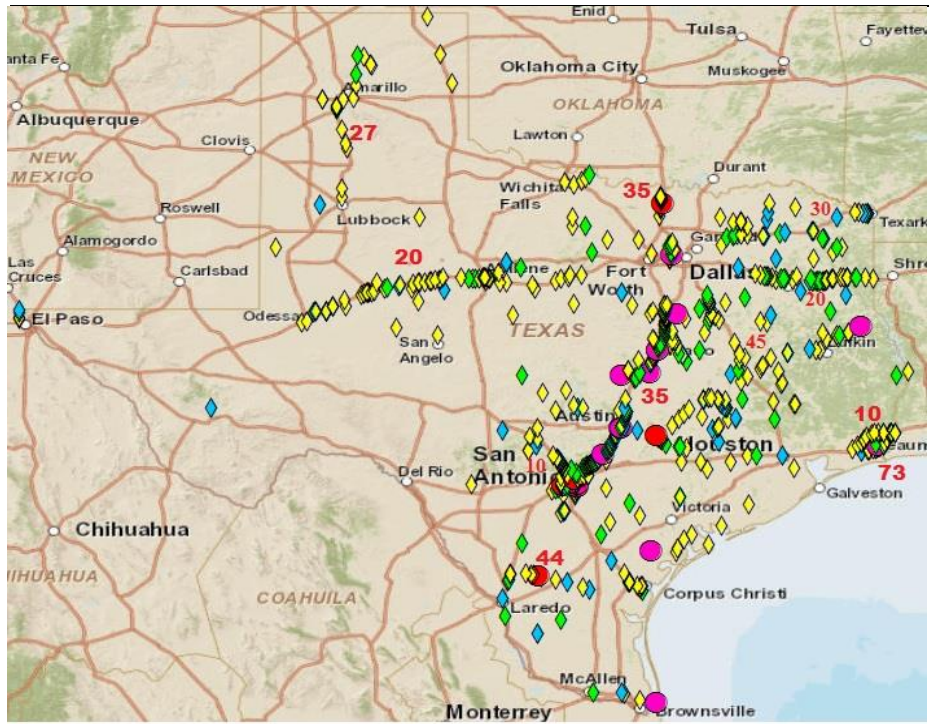
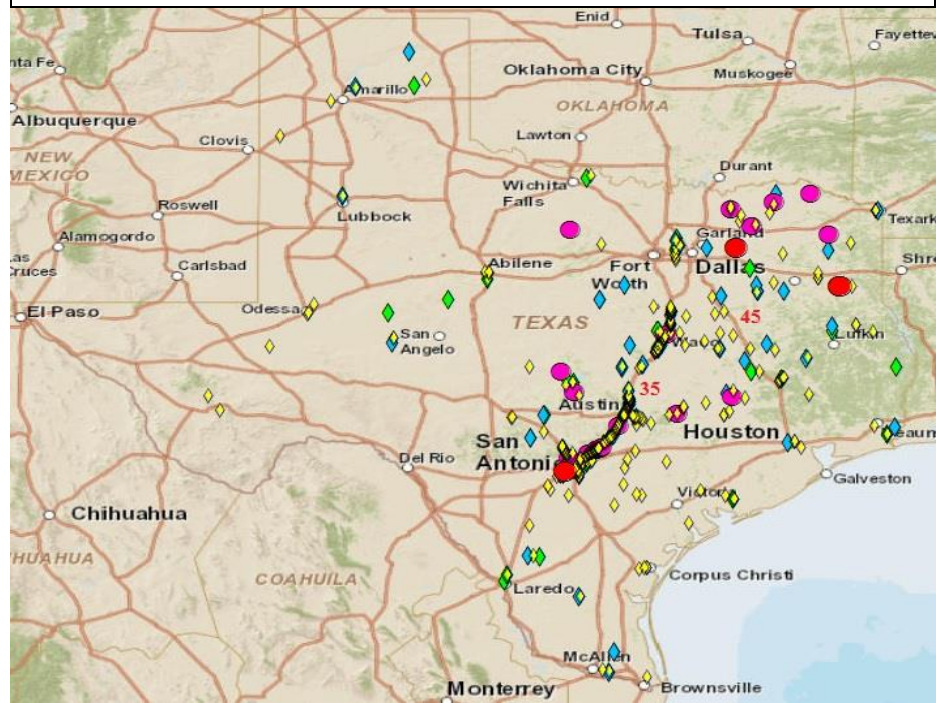


Figure 5: Plotted Crashes by Injury Severity on 70 mph State Highways and Interstates.



2012



2013

Figure 5 Continued.

Figure 6 shows a sequence of plots with crashes occurring on 75 mph posted speed limit state highways and interstates, color-coded by injury severity level, for all four years. From the figure, it can be observed as the number of 75 mph posted speed limit reported road crashes increased, the number of fatal and incapacitating injuries also increased. 2013 shows the most number of reported fatal crashes. However, these crashes are not concentrated in one particular spot. I-20, I-45, and I-10 are shown to be problem areas for K and A injuries in both 2012 and 2013.

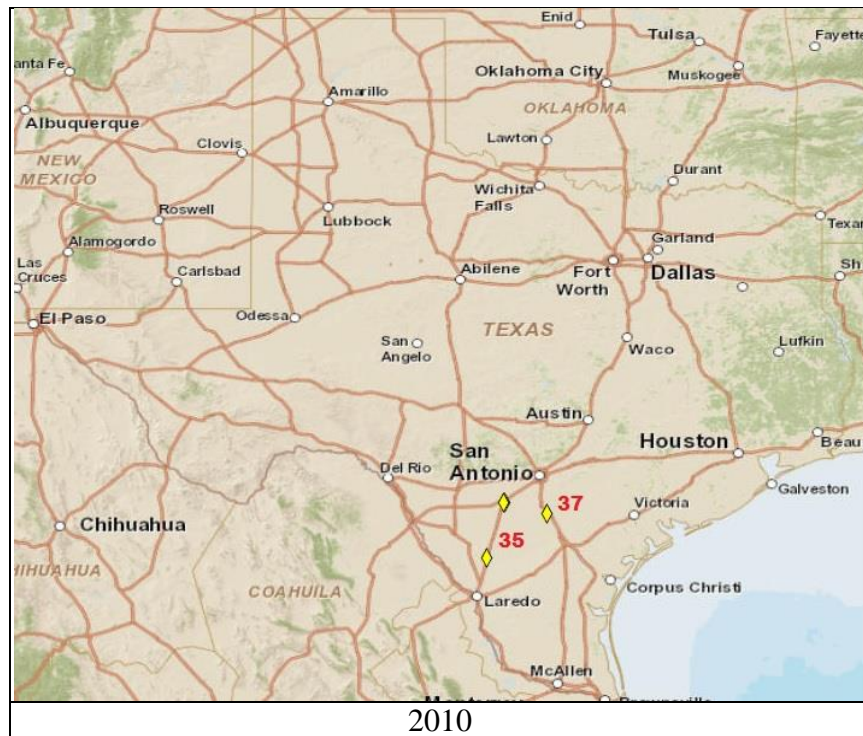
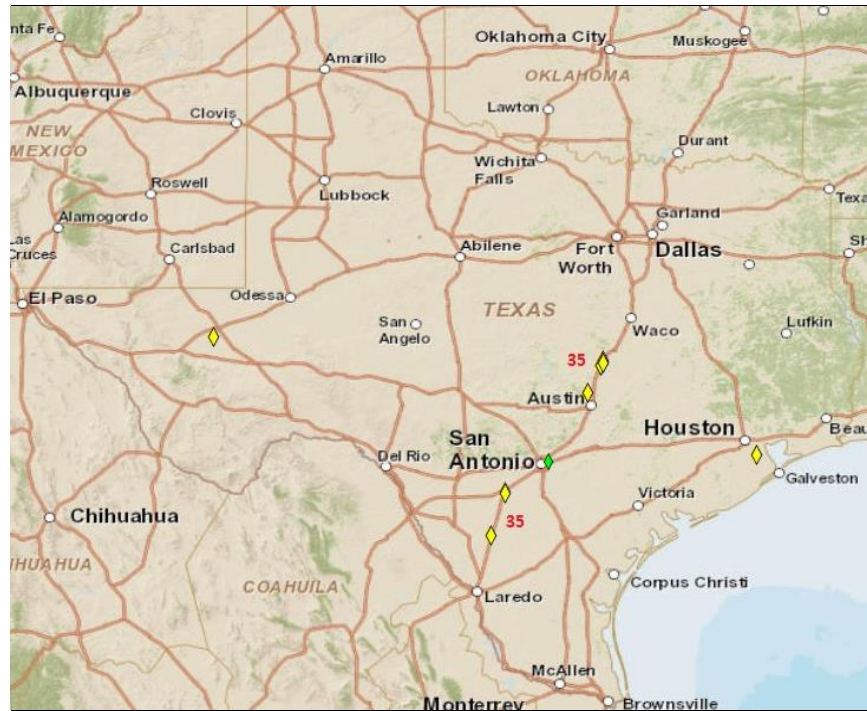
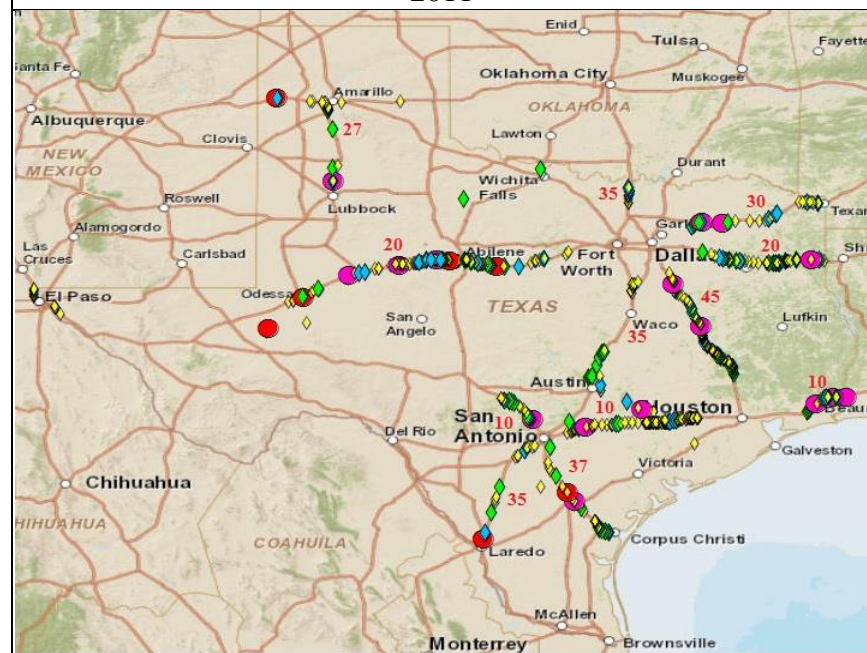


Figure 6: Plotted Crashes by Injury Severity on 75 mph State Highways and Interstates.



2011



2012

Figure 6 Continued.

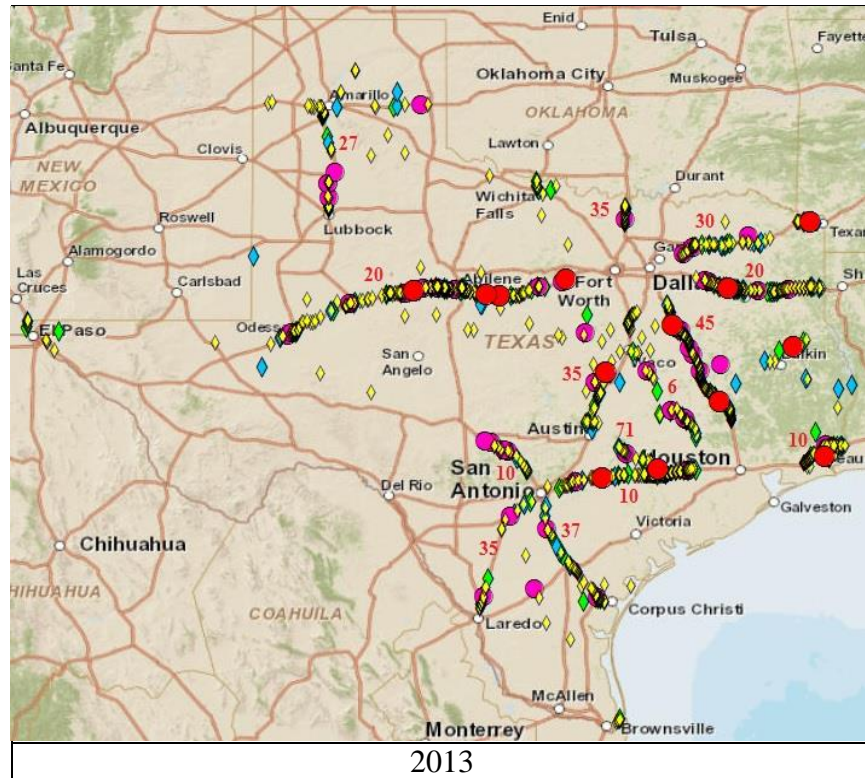


Figure 6 Continued.

Figure 7 shows a sequence of plots with crashes occurring on ≥ 80 mph posted speed limit state highways and interstates, color-coded by injury severity, for all four years. From the figure, it can be observed that more fatal and incapacitating injuries were reported in 2012 and 2013 than in 2010 and 2011. There was a great jump in the number of reported crashes between 2012 and 2013. This could be the result of speed limits being raised to 80 mph. Highway 130 is the road with the 85 mph posted speed limit in 2013, but it only reported not injured or possible injury severity level crashes.

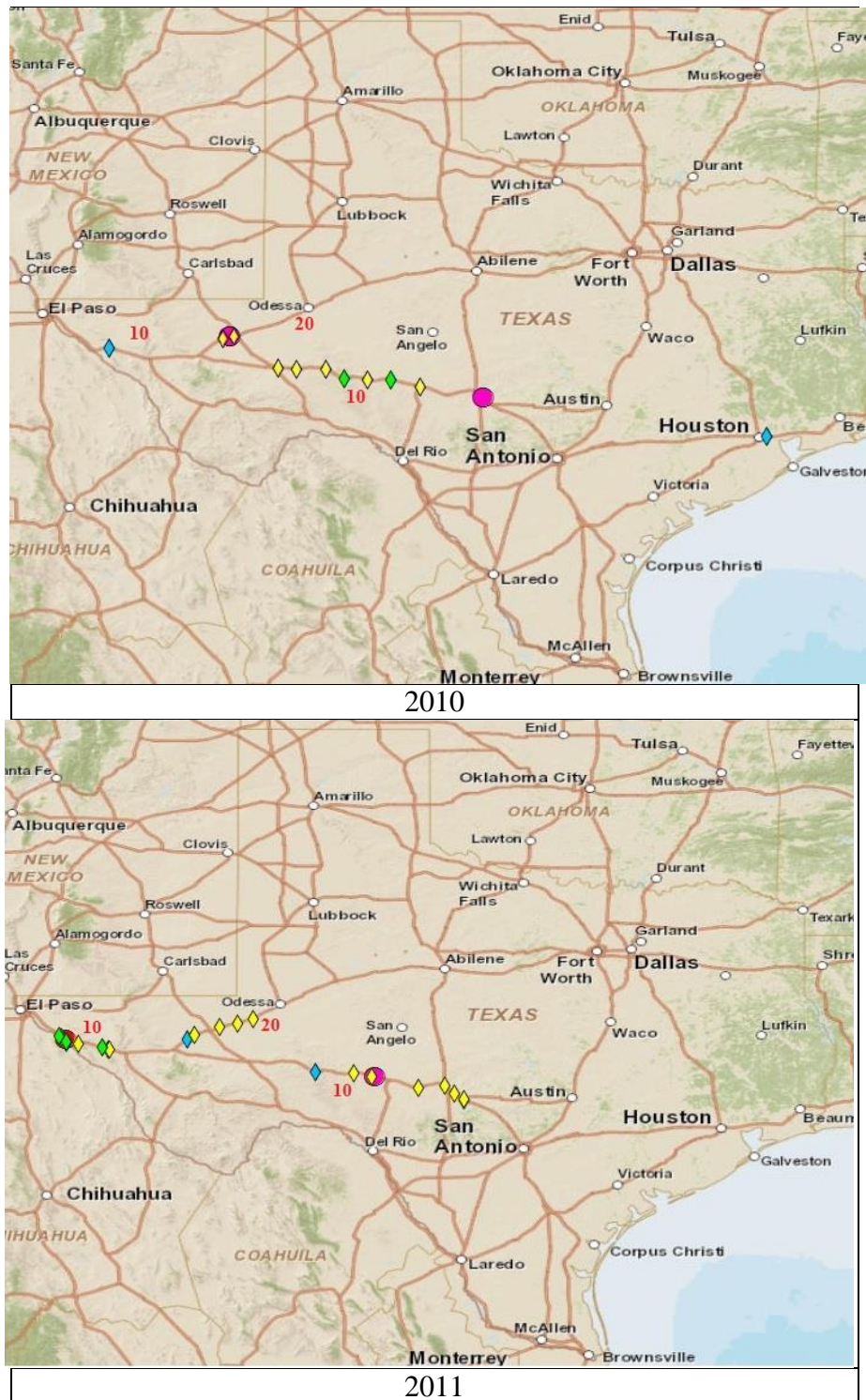
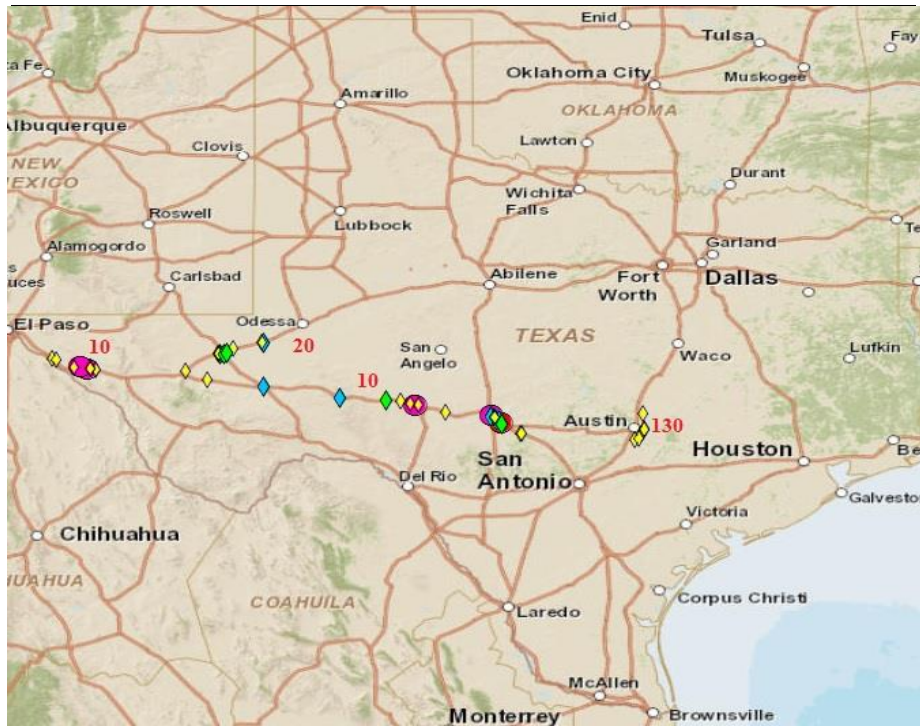
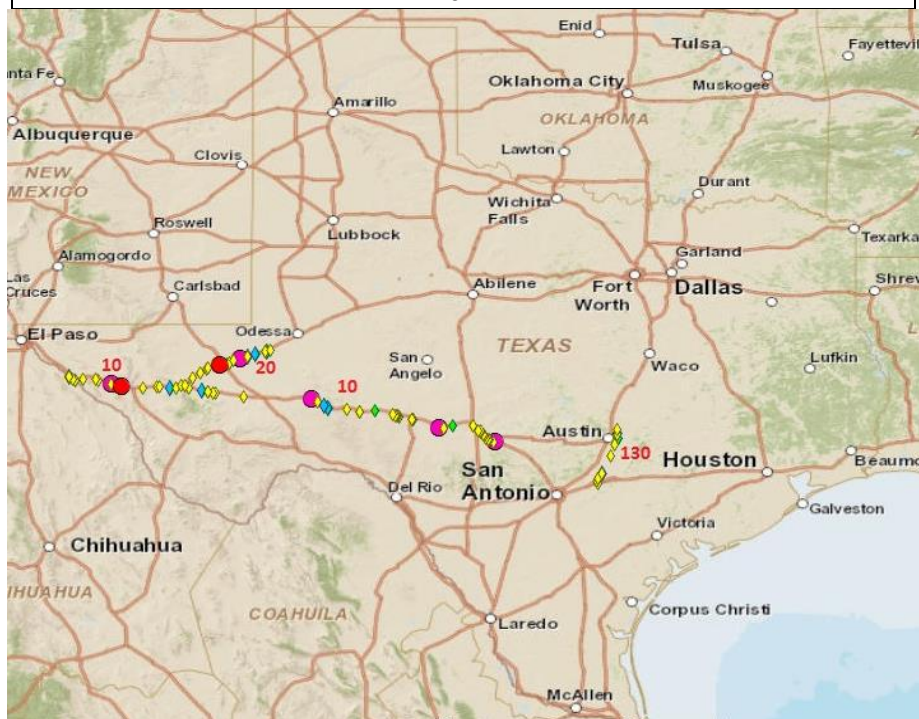


Figure 7: Plotted Crashes by Injury Severity on ≥ 80 mph State Highways and Interstates.



2012



2013

Figure 7 Continued.

Crash Injury Severity Percentages

To quantify the numbers of crashes in each injury severity level for all speed limits, Table 7 shows the numbers of crashes on state highways and interstates for each type of injury severity based on the KABCO scale. Not many fatal crashes were reported for ≥ 80 mph posted speed limit roads because roads with the 85 mph posted speed limit had only opened in 2012. It should be pointed out that SH130 was designed with higher design standards than all existing interstates ("Mobility Corridor (5 R) Design Criteria.").

Table 7: Number of Crashes on State Highways and Interstates by Injury Severity.

Speed Limit (mph):	2010			2011			2012			2013		
	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80
K	7	0	0	13	0	1	7	7	1	3	13	2
A	20	0	2	27	0	1	15	17	4	18	49	5
B	80	0	2	104	0	5	120	72	9	80	109	11
C	117	0	2	134	1	3	125	75	4	69	145	5
O	680	4	7	679	16	13	585	653	27	369	1218	78
Unknown	14	0	1	17	0	0	29	16	0	33	39	1
Total	918	4	14	974	17	23	881	840	45	572	1573	102
Total (no unknowns)	904	4	13	957	17	23	852	824	45	539	1534	101

To observe the changes across all speed limits, the percentages for the injury severity levels were obtained. Table 8 shows the percentages of each type of injury severity based on the KABCO scale for crashes on state highways and interstates. The percentages are respect to the total number of crashes for that speed limit in a specific year, without the unknowns, to reduce the variability in the percentage. Since both fatal and incapacitating injuries were assumed to be a 'severe injury' and the ≥ 80 mph posted speed limit roads had only recently opened and therefore

would not represent an accurate percentage of severe injuries, K and A listed crashes were combined into a single category (K+A). Possible injuries were chosen to be included in the total because of the possibility that they could have been an injury.

Table 8 shows that the K+A percentage category increases from 70 mph to ≥ 80 mph posted speed limit roads. This is consistent for all years. Although 0% of crashes were reported to have a fatal or incapacitating injury in 2010 or 2011 on 75 mph roads, there was a greater than 12% increase in the K+A percentage between 70 mph and ≥ 80 mph in 2010 and a greater than 4% increase in 2011. Years 2012 and 2013 did report crashes with a K or A injury severity level on 75 mph roads and showed an increase in those severity levels as the posted speed limit increased. Along with an increase in the percentage of K+A category, there was a decrease in the percentage of PDO crashes on 70 mph roads to ≥ 80 mph roads for years 2010-2012, suggesting that more crashes resulted in more severe injuries.

Table 8: Percentage of Crashes on State Highways and Interstates by Injury Severity.

Speed Limit (mph):	2010			2011			2012			2013		
	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80	70	75	≥ 80
K+A (%)	2.99	0	15.38	4.18	0	8.70	2.58	2.91	11.11	3.90	4.04	6.93
B (%)	8.85	0	15.38	10.87	0	21.74	14.08	8.74	20.00	14.84	7.11	10.89
C (%)	12.94	0	15.38	14.00	5.88	13.04	14.67	9.10	8.89	12.80	9.45	4.95
O (%)	75.22	100	53.85	70.95	94.12	56.52	68.66	79.25	60	68.46	79.40	77.23
Total (%)	100	100	100	100	100	100	100	100	100	100	100	100

Table 9 combines the K, A, B, C, and O reported crashes for all four years in each speed limit category. Percentages were found with respect to the total number of crashes in each speed limit category. The K+A percentages increase as the posted speed limit increases.

Table 9: Percentages of Crashes on State Highways and Interstates by Injury Severity for Combined 2010-2013 Data.

Speed Limit (mph):	70	75	≥80
K (%)	0.92	0.84	2.20
A (%)	2.46	2.77	6.59
K + A (%)	3.38	3.61	8.79
B (%)	11.81	7.61	14.84
C (%)	13.68	9.29	7.69
O (%)	71.13	79.49	68.68
Total (%)	100	100	100

Figure 8 shows a visual analysis of the data provided in Table 8 by plotting the percentages on charts. The percentages for the K+A category are given for both 70 mph and ≥ 80 mph posted speed limit roads to emphasize the increase in percentage between the two speed limits.

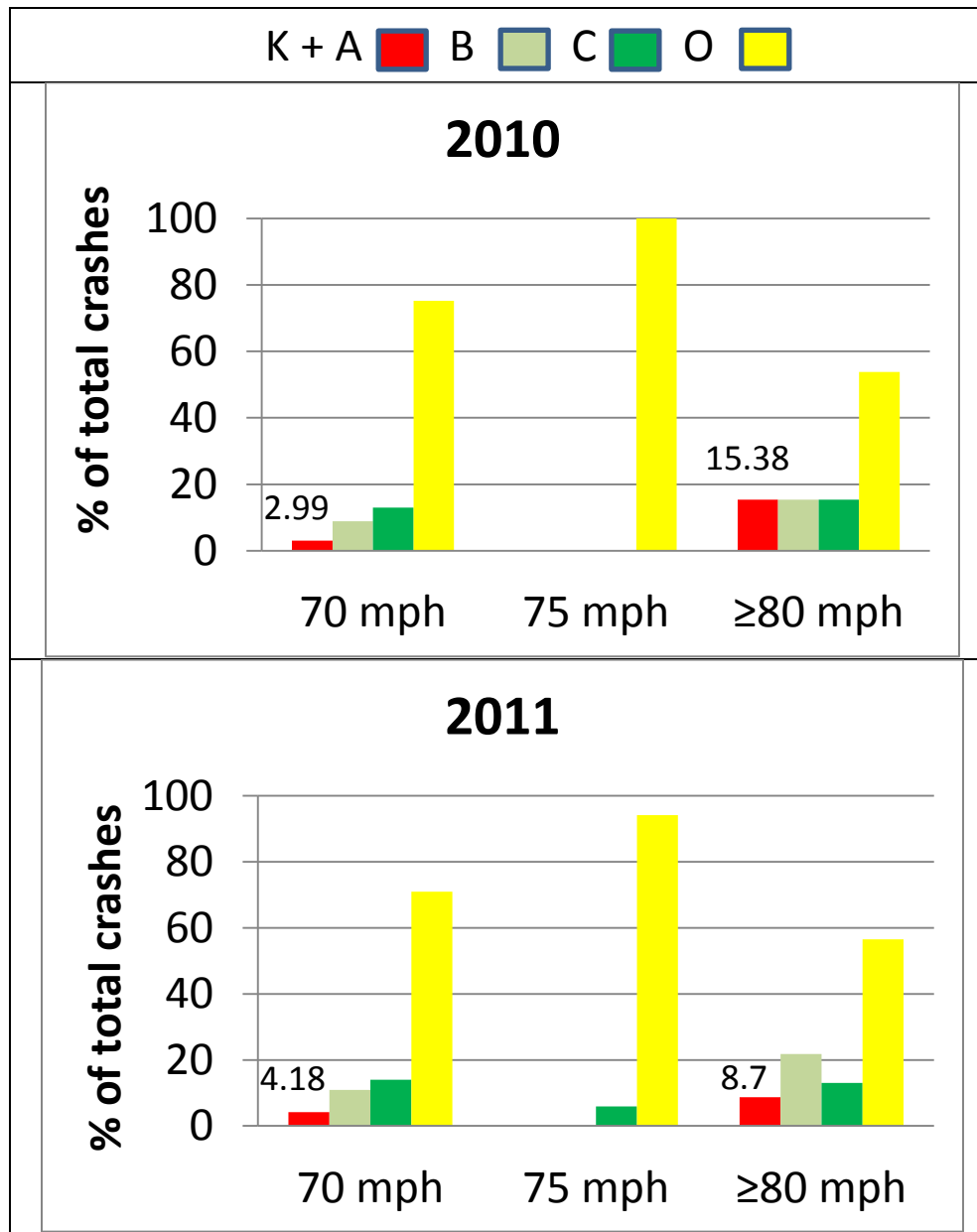


Figure 8: Charts of Crash Severity Injury Percentages for State Highways and Interstates

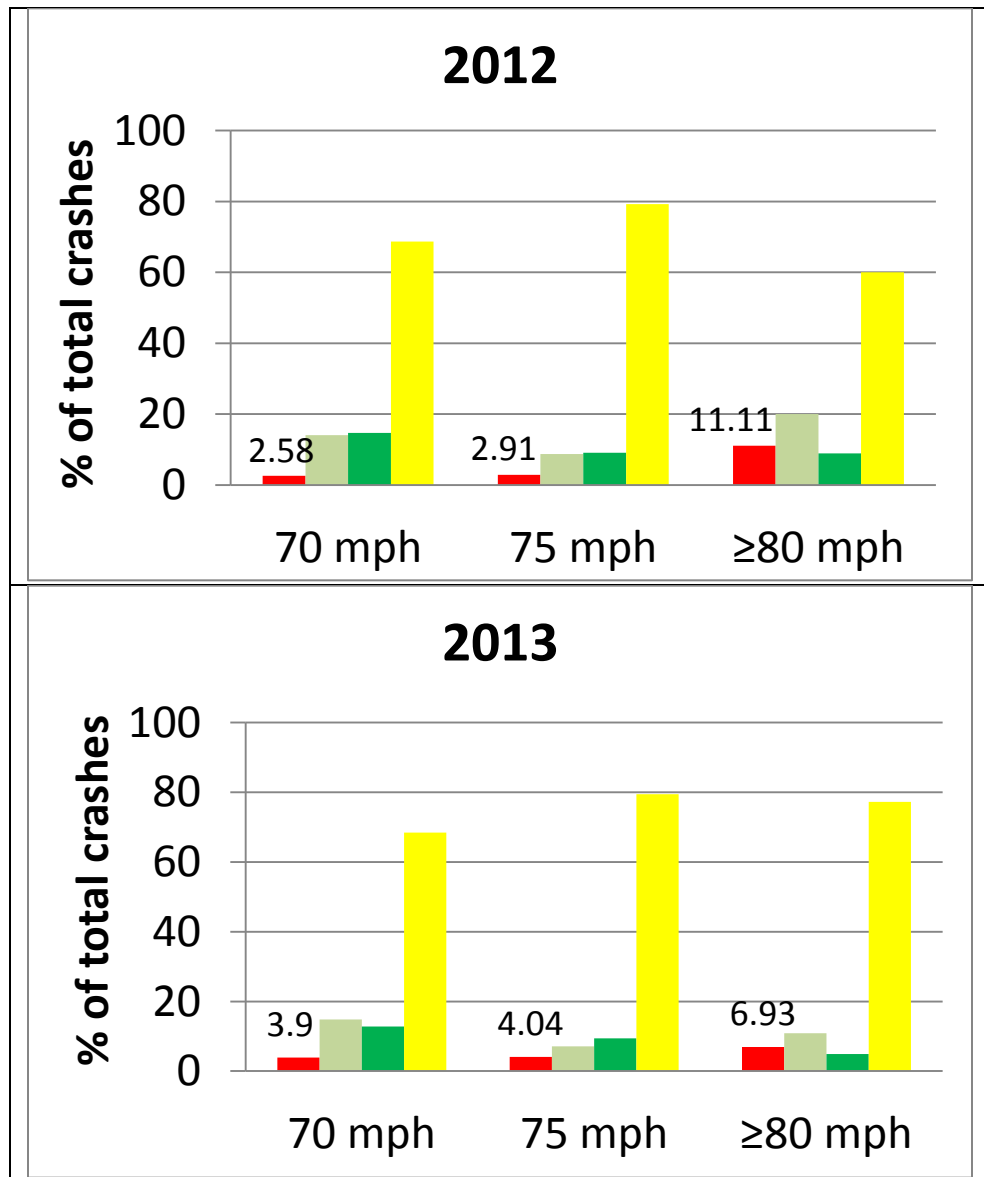


Figure 8 Continued.

Figure 9 shows a visual analysis of the data provided in Table 9 by plotting the percentages on a chart. The percentages for the K+A category are given to emphasize the consistent increase across all speed limit categories.

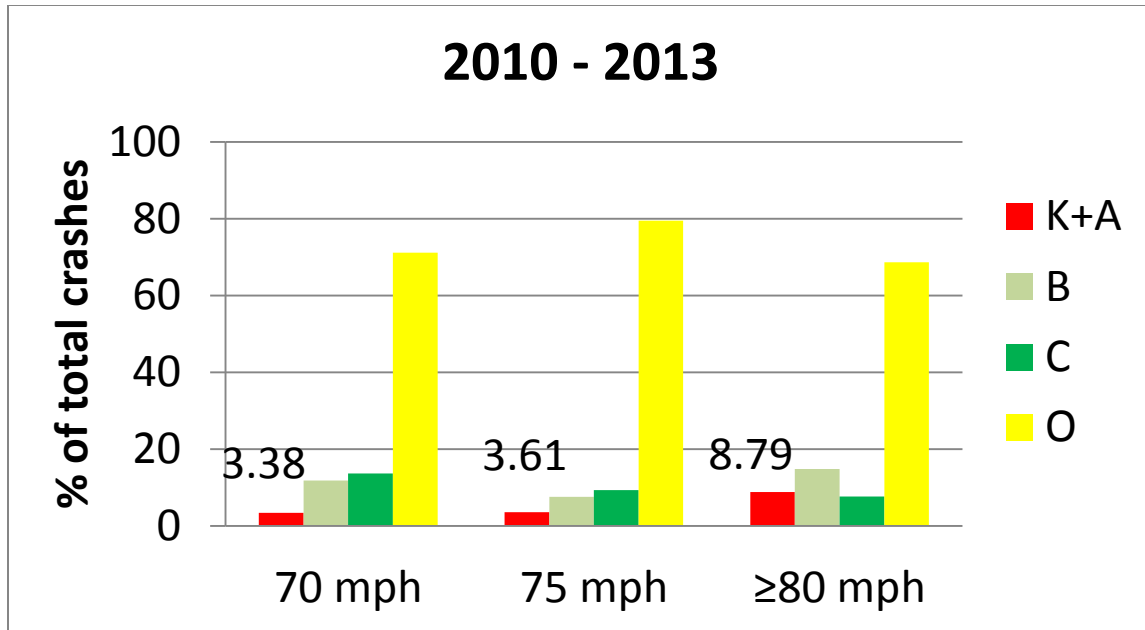


Figure 9: Chart of Injury Severity Percentages of Combined Data.

Statistical Significance

Although it was shown that the fatal and incapacitating injury severity percentages increased as the posted speed limit increased from 70 mph to ≥ 80 mph, the ranges of the means of the two percentages may overlap, indicating that the two percentages are not statistically different. In order to determine statistical significance for the K+A percentages, a 95% confidence interval was performed to determine significance at the 5% level. A confidence level provides a range of values that are likely to contain the true proportion of fatal and incapacitating injuries. In other words, if the analysis was reproduced 100 times, it would be expected that the mean values lie outside the 95% boundaries 5% of the time. The higher the percentage of the confidence interval, the more likely the true value will be assumed to be located within the estimated interval. The following equation was used in computing the confidence interval:

$$\hat{p} \pm Z_{\alpha/2} \sqrt{\frac{\hat{p}\hat{q}}{n}}$$

\hat{p} = proportion of incapacitating and fatal injuries out of the total number of injuries

$$\hat{q} = 1 - \hat{p}$$

$$Z_{\alpha/2} = 1.96$$

n = total number of crashes with reported injuries for that particular year and speed limit

Table 10 provides the results of the computed confidence intervals for the 70 mph and ≥ 80 mph posted speed limit roads for all years as well as for the combined data. The true proportion of fatal and incapacitating injuries is estimated to be within the provided ranges. From the table, it was found that the K+A percentages between the 70 mph and ≥ 80 mph were not statistically different at the 5% significance level since the ranges for these two proportions overlap.

However, the combined data did show significance at the 5% level. The range was higher for the ≥ 80 mph proportion of K+A crashes than for the 70 mph. This indicates that there was an increase in severity as the posted speed limit increased. The reason for the different result for the combined data could be attributed to having a higher sample size.

Table 10: 95% Confidence Intervals for Fatal and Incapacitating Injury Proportions

	70 mph	≥ 80 mph
2010	[0.019, 0.041]	[-0.042, 0.350]
2011	[0.029, 0.054]	[-0.028, 0.202]
2012	[0.015, 0.036]	[0.019, 0.203]
2013	[0.023, 0.055]	[0.020, 0.119]
2010-2013	[0.028, 0.040]	[0.047, 0.129]

Chapter Summary

The plots of the crashes on maps using ArcMap 10.2 showed that the fatal and incapacitating injuries are not concentrated in one particular area, but certain highways reported these more severe injuries consistently for consecutive years. The data for each year shows that the K+A percentage increases as the posted speed limit increases from 70 mph to ≥ 80 mph, suggesting that higher speed limits lead to more severe injuries. The K+A percentage for the combined data showed an increase across all three speed limit categories. However, the K+A percentages between the 70 mph and ≥ 80 mph were not statistically different at the 5% significance level. This was consistent for every year. The K+A percentages for the combined 2010-2013 data showed significance at the 5% level between 70 mph and ≥ 80 mph posted speed limit roads. This difference in results could be that the combined data had a higher sample number and could give a better representation of the percentages. Therefore, data for more years as they become available needs to be investigated to obtain a higher sample size. The increase in injury severity for those roadways with posted speed limit equal to or higher than 80 mph could be attributed to a structural or impact energy absorption inadequacy of the roadside safety barrier(s) placed on these high speed roads. These barriers are full-scale crash tested at a much lower testing speed according to current standards. Therefore, an increase in injury severity suggests that current standards need a higher testing impact speed.

CHAPTER IV

CONCLUSIONS AND FURTHER WORK

This chapter described the summary of the research conducted in this project and explores possibilities for further research. The first section provides an overview of data collected in this project and a summary of the key results. The second section discusses recommendations for future work.

Summary

In this research, data were extracted through TxDOT's CRIS crash database. Characteristics of these data were examined. Injury severity levels were compared for single-vehicle and single occupant ROR crashes occurring against longitudinal barriers on state highways and interstates in 2010-2013. Injury severity levels were compared for the speed limit categories of 70 mph, 75 mph, and ≥ 80 mph. Plots of the crashes for each year and each speed limit category with the KABCO injury severity scale classification were done using ArcMap 10.2. The percentage of crashes in each severity level for each speed limit category and year were found and compared. The fatal and incapacitating injuries were combined to provide more robust results. A 95% confidence interval was performed to determine statistical significance between the 70 mph and ≥ 80 mph K+A severity percentages for all years.

The key study results showed the following:

- Plots of crashes showed that the fatal and incapacitating injuries are not concentrated in one particular area, but some highways experienced more severe injuries consistently for consecutive years.
- The K+A injury severity percentages increased as the posted speed limit increased from 70 mph to ≥ 80 mph.
- The K+A percentages between the 70 mph and ≥ 80 mph were not statistically different at the 5% significance level. This was consistent for every year and was attributed to the small sample size issue.
- The K+A percentages for the combined 2010-2013 data showed significance at the 5% level between 70 mph and ≥ 80 mph posted speed limit roads.
- Since the combined data showed a statistically significant difference, it was concluded that there is a possibility that the severity of injuries increases as the posted speed limit increases. Roadside barriers are designed to absorb impacting energy and limit occupant injuries for the errant vehicle. They are tested at various levels with the highest impacting speed being currently 62 mph. If injury severity appears to increase for impacts against roadside barriers as posted speed limit increases, one suggestion might be that roadside barrier testing and evaluation conditions should be revised to account for a probable higher impacting speed in real world-crashes. It is suggested, however, that data for additional years be analyzed, as they become available. This will allow for a more robust analysis with a larger sample size.

Further Work

Future work should include a detailed review of the original police report. Police reports provide more insight into factors that were involved in the crash, which are not reported in the electronic version. For example, police sketches of the crash scene could provide information on the manner at which the vehicle impacted the barrier. Similarly, the sketches can also show where the barriers were hit (e.g., end treatment, barrier proper), and whether or not the vehicle was redirected into the traffic. Vehicles that impacted on its side tend to result in more severe injuries than vehicles that impacted at an angle, since vehicles are usually better designed to dissipate energy in front-end collisions than broadside collisions. Data could be examined for more years as they become available. Since the first 85 mph road opened in 2012, examining data for more years would make the study of 85 mph roads more robust, as discussed above. With more data to analyze, the injury severity with respect to the exact type of roadside barrier could be examined. If needed, the reconstruction of crashes could be performed to find the impact speed of the vehicle against the barrier. Future studies could use the information from these resources to make a more conclusive statement about a need for review of the testing impact speed condition required for evaluation of those roadside barriers to be placed on high speed roads (≥ 80 mph).

REFERENCES

Bligh, Roger, Nauman Sheikh, Akram Abu-Odeh, and Wanda Menges. "Evaluation of Barriers for Very High Speed Roadways." Texas Transportation Institute Proving Ground FHWA/TX-10/0-6071-2 (2010). Print.

"Crash Data Analysis and Statistics." Texas Department of Transportation. Web. 26 Jan. 2015. <<http://www.txdot.gov/inside-txdot/division/traffic/crash-statistics.html>>.

Fitzpatrick, Kay, Karl Zimmerman, Roger Bligh, Susan Chrysler, and Byron Blaschke. "Criteria for High Design Speed Facilities." Texas Transportation Institute FHWA/TX-07/0-5544-1 (2007). Print.

LeBeau, Phil. "Fastest Road in America: 85 MPH and We May Be Going Even Faster." CNBC. 23 Oct. 2012. Web. 21 Aug. 2014. <<http://www.cnbc.com/id/49520151#>>.

"Mobility Corridor (5 R) Design Criteria." Roadway Design Manual. 2014. Print.

Sheikh, Nauman, Rubiat Ferdous, Roger Bligh, and Akram Abu-Odeh. "Analysis of Roadside Safety Devices For Use On Very High-Speed Roadways." Texas Transportation Institute FHWA/TX-09/0-6071-1 (2009). Print.

"Speed." Highway Safety Research & Communications. Insurance Institute for Highway Safety, 1 Mar. 2015. Web. 31 Mar. 2015. <<http://www.iihs.org/iihs/topics/laws/speedlimits/mapmaxspeedonruralinterstates?topicName=Speed>>.